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# ANALYSING DIFFERENCES BETWEEN THE INPUT IMPEDANCES OF FIVE CLARINETS OF DIFFERENT MAKES

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## 1 INTRODUCTION

Physical differences, such as variations in geometry, between musical wind instruments of a given type generally lead to differences in their resonance properties and, consequently, in their playing characteristics. Input impedance measurements provide information about both the strengths and frequencies of the instrument's air column resonances. In most playing situations, it is these air column resonances, rather than the reed or lip vibrations, that control the oscillation. Consequently, impedance curves can impart a great deal of information about the playing characteristics of an instrument.

In this paper, input impedance measurements on five clarinets are discussed and a new method of presenting impedance data is described. The method enables impedance differences between instruments to be plotted across the whole note range, facilitating identification of any general trends between those instruments.

The instruments chosen for this study were five student model clarinets made by different manufacturers: a Boosey and Hawkes Regent instrument, a Buffet B12 instrument, a Corton instrument, a Jazzo instrument and a Yamaha 34IIS instrument (Figure 1). Different makes of elementary level clarinets were selected as it was anticipated they should display significant physical and acoustical differences. The instruments were made by manufacturers based in different countries so it is probable that there are differences in their design and playing properties.



Figure 1 Clarinets measured in the study.

## 2 INPUT IMPEDANCE MEASUREMENTS

Input impedance is defined as the complex ratio of pressure to volume flow at the input of a tubular object such as a wind instrument.<sup>1</sup>

$$Z = \frac{P \text{ (pressure amplitude)}}{U \text{ (volume velocity)}}$$

A popular means of determining the input impedance of a musical wind instrument is to use a capillary-based measurement system. A loudspeaker is driven over the frequency range of interest and the resultant acoustic signal is passed via a capillary into the instrument under test. A microphone positioned at the input to the instrument measures the resultant pressure response. The high-impedance capillary effectively decouples the instrument from the measurement system, ensuring that the volume velocity of the acoustic excitation signal is independent of the object being measured. Therefore, by calibrating the system with theoretically known impedances, this volume velocity can be determined. The input impedance of the instrument under investigation can then be found by dividing the measured pressure response by the volume velocity.<sup>2</sup>

In this study, input impedance is measured using two different capillary-based measurement systems. Firstly, measurements are conducted using the Brass Instrument Analysis System (BIAS), and secondly using an in-house system.

### 3 MEASUREMENTS ON BIAS

BIAS is a commercially available input impedance measurement system.<sup>3</sup> The measurement head uses three bundles of capillaries in a triangular formation (with a single microphone positioned in the centre of the triangle). It is primarily designed for the testing of brass instruments, and its coupling system has been optimised to ease the attachment of such instruments. However, bespoke couplers can be produced to enable measurements on woodwind instruments. For example, in [4] a coupler is described which allows an oboe with staple to be attached to the BIAS head.

Coupling a complete clarinet (including mouthpiece) to the BIAS head presents a greater challenge. The threaded metal sleeve and bayonet locking ring that comprise the BIAS coupling system do not enable instruments to be mounted transversely. To try to overcome this, a coupler with an embedded mouthpiece was constructed and a new locking sleeve was designed (see Figure 2). However, the rectangular window in the clarinet mouthpiece was found to be fractionally too narrow to fit over the triangular arrangement of capillaries on the BIAS head.

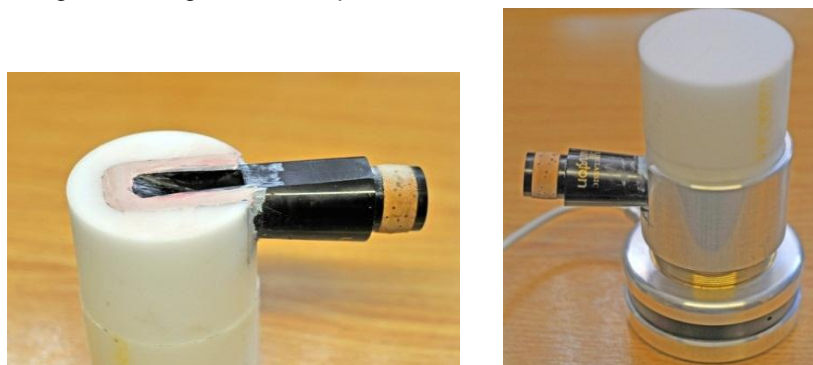


Figure 2 Clarinet coupler with mouthpiece embedded; mouthpiece coupler in the BIAS head.

In order to carry out clarinet measurements using BIAS, a second coupler was produced which allows a clarinet to be mounted vertically but with the mouthpiece removed. The coupler, pictured in Figure 3, contains a cylindrical volume equivalent to that contained within the mouthpiece ( $11.9 \text{ cm}^3$ ). The volume was determined by filling a mouthpiece with water and transferring the water to a measuring cylinder. This coupler is inserted into the barrel of the clarinet and is then clamped to the BIAS head in the usual way (Figure 3).



Figure 3 Cylindrical coupler with BIAS set-up.

## 4 ANALYSIS OF IMPEDANCE CURVES OVER WHOLE PITCH RANGE

Input impedance measurements for all note fingerings from E3 to G6 in semitone intervals (40 notes in total) were made on all five clarinets using the BIAS system with cylindrical coupler. Each measurement could be completed in a matter of seconds; therefore it was possible for the player to apply note fingerings directly during measurement. An example of the impedance magnitude curves measured on the five instruments with the A4 fingering applied is shown in Figure 4.

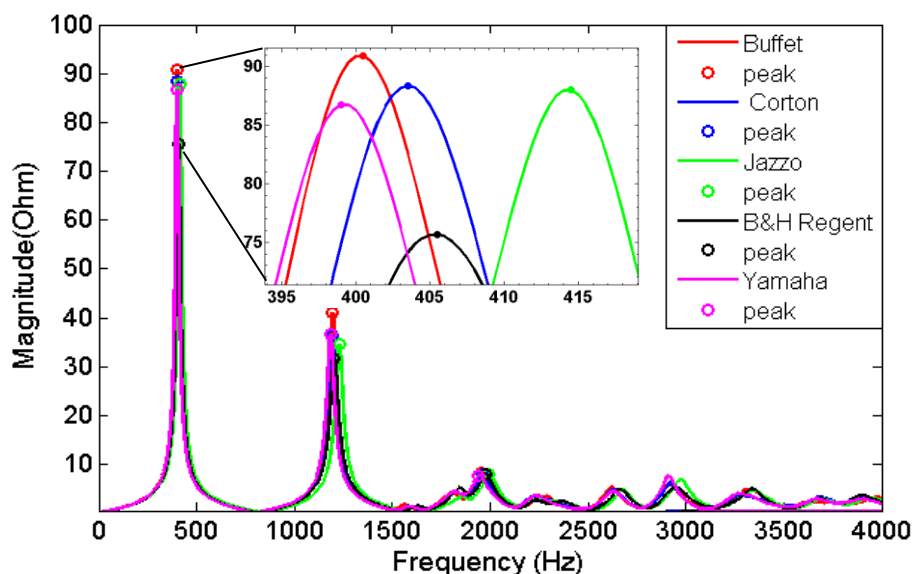


Figure 4 Impedance magnitude curves for five clarinets for note A4.

To investigate differences in input impedance between the five clarinets across the whole pitch range of the instrument using plots of the type shown in Figure 4 would involve examining 40 individual graphs. To avoid this necessity, a new method of analyzing batches of impedance curves was introduced by Mamou-Mani et.al.<sup>4</sup> This method is employed here. At each note pitch, average values for the amplitudes and frequencies of each of the resonance peaks are calculated from the five clarinet impedance curves. For each of these impedance curves, the differences in the amplitudes and the differences in the frequencies of each of the resonance peaks from their corresponding average values are then determined. These differences are then plotted on a scatter diagram with the difference in frequency plotted in cents on the x-axis and the relative difference in amplitude plotted on the y-axis.

An example of such a scatter diagram can be seen in Figure 5 which plots deviations in the frequencies and amplitudes of the first resonance peaks from the corresponding average values for the five clarinets under investigation for notes in the first register (E3-Bb4). It is immediately apparent that the notes for each instrument tend to be clustered together on the plot, creating five distinct groupings. In general, the tighter the clustering of the frequency differences for a given instrument, the more consistent the intonation of the instrument across its playing range (although it should be noted that higher resonances will also have an effect). It can be seen that the Jazzco clarinet shows quite a large spread in terms of the difference in the frequency of the first resonance peak from the average value, ranging from a difference of about 5 cents (for the note E3) to a difference of about 45 cents (for the note Bb4). Indeed, closer inspection reveals that the deviation in frequency becomes markedly greater towards the top of the register. This suggests that the instrument has rather inconsistent tuning across the first register, with a tendency for the higher notes in the register to play very sharp. This assertion is backed up by informal playing of the instrument.

It is also worth noting that for all the measurements displayed in Figure 5, the coupler was fully inserted into the barrel. If the coupler had been pulled out a little when measuring the Jazzco instrument, the observed frequency deviations would have been less pronounced (the green points on the graph would have been shifted to the left). The spread of values may also have been reduced. This is in line with a player pulling the mouthpiece out slightly when an instrument is playing sharp in order to bring it into tune.

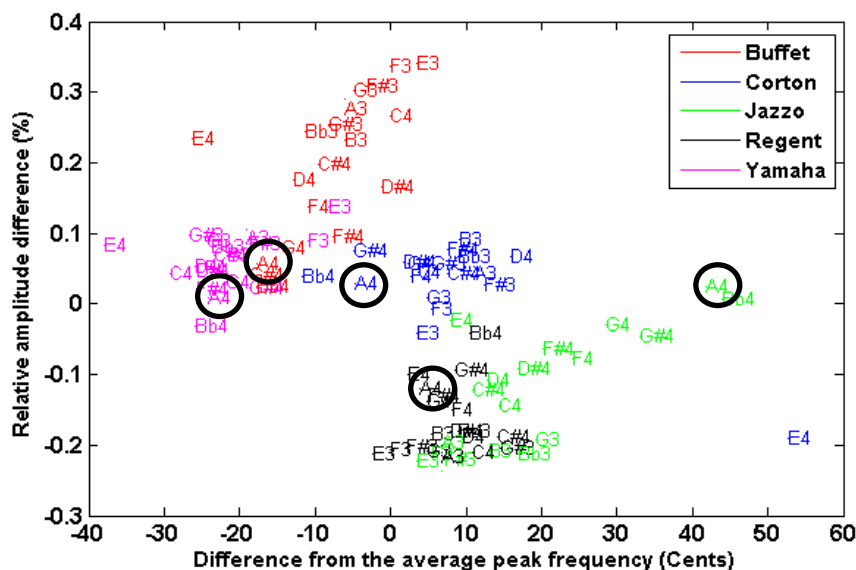


Figure 5 Scatter diagram plotting deviations in the frequencies and amplitudes of the first resonance peaks from the corresponding average values for the five clarinets under test for notes in the first register (E3–Bb4).

Scatter plots of this type have proved particularly useful when analysing instruments of the same make and model, as was the case in [4] where a set of nominally identical oboes was investigated. On the other hand, the five clarinets used in the current study are made by different manufacturers and therefore display greater differences. This raises some issues. If one instrument has resonance characteristics that are significantly different from the others then it will have an undesired effect when the average frequency and amplitude values for each resonance peak are calculated across the instruments. The result is that the frequency and amplitude deviations from the average values for the other four instruments will be adversely influenced by the outlier instrument.

For example, Figure 4 shows impedance magnitude curves for the five clarinets when the A4 fingering is applied. It can be seen that the frequency of the first resonance peak is much higher (at

about 415 Hz) for the Jazzo clarinet than for the other instruments (between about 399 Hz and 406 Hz). From this, it might be concluded that, when the A4 fingering is applied, for best performance a clarinet should have a first resonance frequency of around 403 Hz (give or take 3 or 4 Hz), and that the Jazzo instrument is an outlier that doesn't meet this criterion. However, in the plotting method described above, the first resonance frequency of the Jazzo instrument contributes to the average value. The calculated average value is therefore not truly representative (it is higher than would be observed in most clarinets). The effect of this can be seen in Figure 5. As expected the Jazzo A4 point appears over to the right of the scatter diagram, indicating that the first resonance peak has a higher frequency than the calculated average. However, with the A4 fingering applied, three of the other instruments (Yamaha, Buffet and Corton) appear to the left of the scatter diagram with lower first resonance frequencies than the calculated average while the other instrument (Regent) has a first resonance frequency that is only a little higher than the calculated average. The effect of the unrepresentatively high average value is to shift all the points towards the left.

To overcome this issue, a variation of the plotting method was considered. In this variation, at each of the 40 note pitches, median values (rather than average values) for the amplitudes and frequencies of each of the resonance peaks are found from the five clarinet impedance curves. For each of the impedance curves, the differences in amplitude and frequency of each of the resonance peaks from their corresponding median values are then determined and plotted as before. Figure 6 shows the data of Figure 5 replotted in this way.

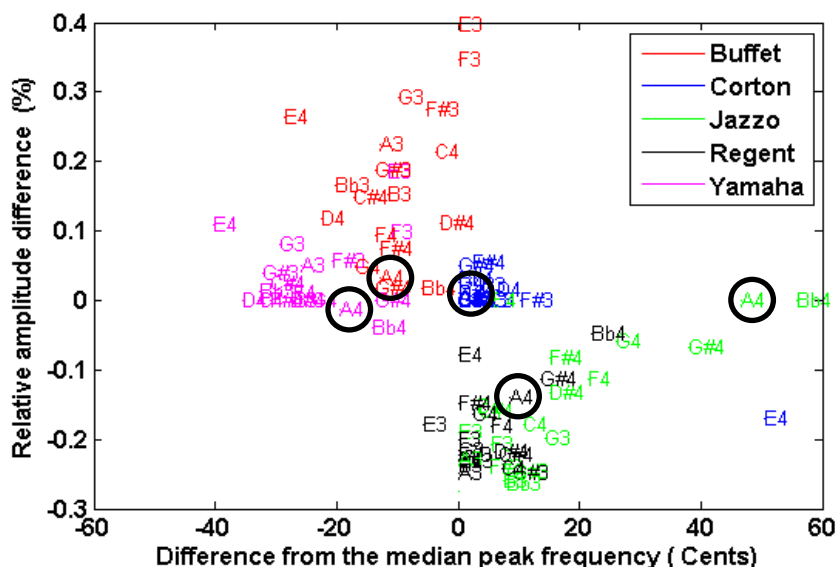


Figure 6 Scatter diagram plotting deviations in the frequencies and amplitudes of the first resonance peaks from the corresponding median values for the five clarinets under test for notes in the first register (E3–Bb4).

By using the median values, the effect of an outlier instrument on the calculated frequency and amplitude differences for the other four instruments is removed. By comparing Figure 6 with Figure 5, it can be seen that the A4 points are now all shifted to the right, with the Yamaha, Buffet, Corton and Regent instruments having first resonance frequencies all quite close (within 20 cents) to the median value. (The first resonance frequency for the Jazzo is still, as expected, much higher than the median value.)

There is one slight drawback to using median values when calculating the frequency and amplitude deviations of the resonance peaks. At each note value, for each resonance peak inherently there will be one instrument whose resonance frequency has zero difference from the median value and similarly there will be one instrument whose resonance amplitude has zero difference from the

median value. This is the reason why a fifth of the points in Figure 6 sit along the x-axis and a fifth of the points sit along the y-axis.

To reduce this element of discretization, a further variation of the plotting method was developed. In this case, at each note pitch, the amplitudes and frequencies of each of the resonance peaks are extracted from the five clarinet impedance curves. Then, for each resonance peak, the highest and lowest frequency values are discarded and the remaining three values are averaged. Similarly, the highest and lowest amplitude values are discarded and the remaining three values are averaged. For each of the impedance curves, the differences in amplitude and frequency of each of the resonance peaks from their corresponding “3 point average” values are then determined and plotted as before. Figure 7 shows the data of Figures 5 and 6 replotted in this new way.

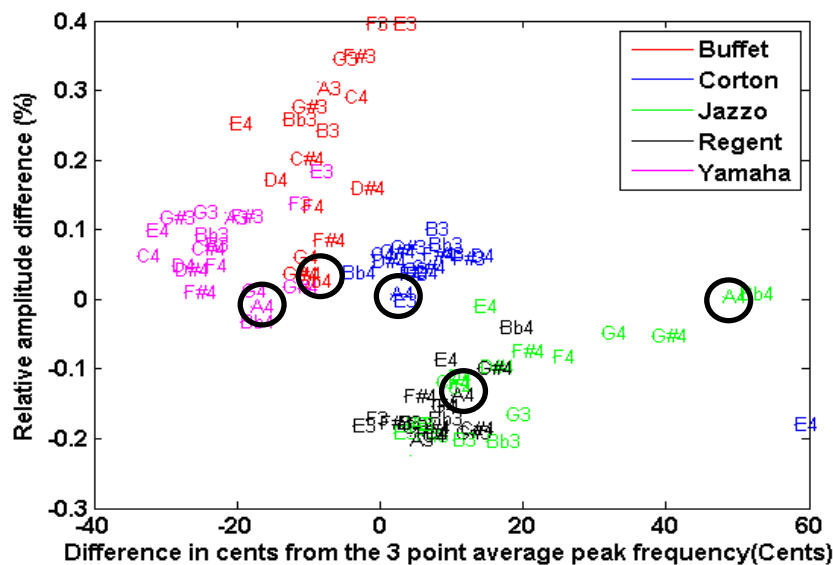


Figure 7 Scatter diagram plotting deviations in the frequencies and amplitudes of the first resonance peaks from the corresponding “3 point average” values for the five clarinets under test for notes in the first register (E3–Bb4).

By discarding the highest and lowest amplitude and frequency values for each resonance peak before calculating the average values, the effect of an outlier instrument has again been removed. Again, comparing Figure 7 with Figure 5, the A4 points are now all shifted to the right, with the Yamaha, Buffet, Corton and Regent instruments having first resonance frequencies all quite close (within 20 cents) to the “3 point average” value. This is similar to what was observed in Figure 6. However, in Figure 7, there is no longer a forced concentration of points along the axes, enabling more subtleties in the impedance differences between instruments to be observed.

## 5 MEASUREMENTS ON OU SYSTEM

The ultimate aim of this study is to try to correlate differences in the resonance properties of musical wind instruments with differences in their perceived playing properties (established through psychoacoustical testing). Therefore, when determining the input impedances of the five clarinets, it is desirable to be able to carry out measurements on the full instrument including mouthpiece.

As the spacing of the triangular arrangement of capillaries in the BIAS head is fractionally too large to be covered by the rectangular window of a clarinet mouthpiece, it is only possible to use BIAS to measure clarinets without the mouthpiece present (using a cylindrical coupler of equivalent volume). The Open University in-house impedance measurement system (described previously by Sharp *et*



*al.*<sup>2)</sup> has a single capillary located immediately next to the microphone in the centre of a large metal plate. Their spacing is such that the rectangular window in a clarinet mouthpiece can easily cover them both, enabling full clarinets to be measured on the apparatus.

The system provides very accurate measurements of complex input impedance but, in order to maintain a high signal-to-noise ratio, a complete measurement across the frequency range of interest can take up to 10 minutes. This longer measurement time (compared with BIAS) means that, when measuring woodwind instruments, it is often desirable to apply some form of clamping to the keys when investigating different fingering combinations. Alternatively, a player can apply fingers directly during measurement.

When measuring full clarinets on the in-house system, it can be difficult to achieve a repeatable coupling with the metal plate due to the curved face of the clarinet mouthpiece. To address this, the coupler of Figure 2 is used. This coupler (in which a clarinet mouthpiece is embedded) provides a flat contact surface to facilitate sealing the mouthpiece to the metal plate. Even with this coupler, measurements can be very sensitive to small changes in its positioning and sealing. Initially, petroleum jelly was applied to the plate to try to create an airtight seal between it and the mouthpiece coupler. However, consistent results were not achieved this way. Instead, inserting a rubber pad (similar to that used with BIAS) between the plate and the coupler and applying a load on top of the coupler has been found to give a good, reliable seal.

Input impedance measurements are currently being made on the five clarinets for all notes in the playing range. The measurements are ongoing but for those notes in the first register that have been measured so far, Figure 8 shows a scatter diagram plotting the differences in the frequencies and amplitudes of the first resonance peaks from the corresponding “3 point average” values. Although not all the notes in the first register have yet been measured, it is clear that a similar pattern is emerging to that seen in Figure 7.

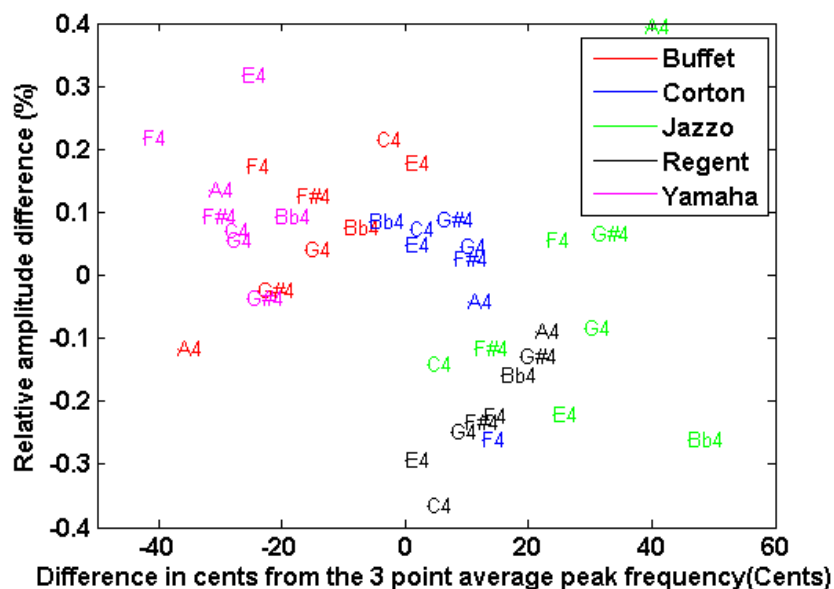


Figure 8 Scatter diagram plotting deviations in the frequencies and amplitudes of the first resonance peaks from the corresponding “3 point average” values for the five clarinets under test for notes C4, E4-Bb4.

## 6 CONCLUSION

There are practical issues when attempting to carry out input impedance measurements on full clarinets using capillary-based apparatus. The dimensions of the rectangular window in a clarinet



mouthpiece are too small for it to cover the capillary/microphone arrangement on a commercially available BIAS head. Therefore, to make clarinet measurements using BIAS, a bespoke cylindrical coupler needs to be used in place of the mouthpiece. The capillary/microphone separation on an in-house measurement system is small enough to be covered by the mouthpiece window. However, the curved face of the mouthpiece makes it difficult to achieve a reliable coupling to the measurement plate, requiring the mouthpiece to be embedded in a specially-manufactured coupler to provide a flat contact surface.

Input impedance measurements across the note range have been made on five clarinets using BIAS and the in-house system. For any given note, impedance differences between the instruments can be investigated by comparing the five measured impedance magnitude curves. However, to facilitate looking for impedance differences across the whole playing range, a new method of presenting the impedance data has been developed and improved. This method provides a scatter plot showing, at each note pitch, the differences in the frequencies and amplitudes of the resonance peaks of the five clarinets from specific reference values. When average resonance peak frequencies and amplitudes were used as the reference values, it was discovered that an outlier instrument could have an adverse effect on the positioning in the scatter diagram of points corresponding to other instruments. To remove this effect, it was found more useful to use either median or “3 point average” resonance peak frequencies and amplitudes as the reference values.

Scatter plots of this type provide a wealth of information regarding the impedance differences between a set of instruments. With careful interpretation, conclusions about the relative playing properties of those instruments can then be made. The results presented in this paper form the first stage of this process for the five clarinets currently being investigated.

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